X-ray and UV imaging with multi-GEM/MHSP gaseous detectors

J.M. Maia[a,b,c], A. Breskin[a], R. Chechik[a], J.F.C.A. Veloso[d], J.M.F. dos Santos[c]

[a]Dept. of Particle Physics, The Weizmann Institute of Science, 76100 Rehovot, Israel
[b]Physics Dept., University of Beira Interior, 6201-001 Covilhã, Portugal
[c]Instrumentation Center, Physics Dept., University of Coimbra, 3004-516 Coimbra, Portugal
[d]Physics Dept., University of Aveiro,3810-193 Aveiro, Portugal

***Abstract* – We present the recent results regarding the application of cascades of GEMs and a MHSP in the detection and imaging of X-rays and UV-photons. The imaging system tested consisted in a micropattern gas detector based in multi-GEM or multi-GEM/MHSP electron multipliers, a 20×20 mm^2 Wedge & Strip (W&S) readout electrode with 1.6 mm pitch positioned below and at close distance of a resistive electrode, and a position enconding electronics with a DAQ system. Spatial resolutions in the *x* and *y* coordinates lower than ~100 μm RMS, were measured in Ar/5%CH_4 gas mixture at atmospheric pressure.**

I. INTRODUCTION

The application of the microelectronics technology for the manufacturing of the micropattern radiation detectors such as MSGCs, Micromegas, and several "hole-multipliers", such as the GEMs, MHSPs, THGEMs, Capillary-plates, etc [1–4], opened the possibility of the application of photon-counting technique in medical X-ray imaging, e.g. in digital radiography [5], despite its majority applications be in particle physics experiments. The high granularity, i.e. small amplification cells in the order of few hundred of μm, offers a very high spatial resolutions, high time resolutions and high counting-rate capability. In medical X-ray imaging items as the dose of X-rays delivered to the patient, the high spatial resolution and the operation at high photon flux (>10^5 Hz/mm^2), should be very well addressed, imposing large requirements on this new gas micropattern detectors, which should measure individual photon energies.

In the last two decades a huge research have been done towards the development of digital radiography devices with the capacity of photon-counting, to replace screen/film systems in medical X-ray imaging, which operate on the principle of energy integration. This opens the possibility of X-rays dose reduction during the image acquisition, with the very well known advantages to the patients. A imaging system based in a gas micropattern detector combining a GEM and a MSGC was applied with success in photon-counting digital radiography [6], demonstrating a high spatial resolution (typically ~50 μm RMS) comparable to that of screen/film system. Another imaging gas detector based in a high-resolution microgap Resistive Plate Chamber (RPCs) [7], have been described with excellent single X-ray detection and imaging properties; it can operate at a counting rate of 10^5 Hz/mm^2 with a spatial resolution less than 50 μm RMS in digital mode, allowing that fine details of a small animal body be well resolved. Taking in account the possible applications in medical diagnostics, a multi-GEM based multiplier have been developed for digital absorption radiography [8] and a spatial resolution lower than 100 μm RMS was obtained. The high rate capability of multi-GEM detectors, above 10^5 Hz/mm^2, the good position resolution, the robustness and radiation hardness make them good candidates for digital medical diagnostics and portal imaging.

Up to now, the detector technology for Positron Emission Tomography (PET) was dominated by scintillating materials (e.g. BGO) followed by photomultipliers tubes (PMTs) [9]. Recently, due to the advances in the development of new photodetectors, an increasing interess was manifested in exploit these new fields for PET applications. Various types o gas detectors have superior intrinsic homogeneity and can provide excellent position resolution at low cost. The low efficiency for γ-rays can be improved working at pressures higher than the atmospheric, or at atmospheric pressure and low temperature. For example, micropattern gaseous photomultipliers (GPMs) [10], which combines a gas electron multiplier structure (e.g. a multi-GEM electron multiplier) with a solid UV-sensitive photocathode, namely CsI deposited in the top of the first GEM in cascade, can be used for large area applications, at a modest cost, and can be operated in high magnetic fields. Recently, it was suggested the use of GPMs for the detection of both the ionization and scintillation signals in two-phase avalanche detectors [11]. In order to improve the detection efficiency in PET applications, the γ-rays should interact in the liquid phase and both scintillation photons and primary ionization will be read by a GPM in the gas phase; an approach consists of combining a LXe (liquid Xenon) converter with a large-area fast gas-avalanche imaging photomultiplier (GPM) [12].

In this work we summarize our main results of X-ray imaging obtained with multi-GEM and multi-GEM/MHSP based gas detectors, and of UV-photon imaging with GPMs combining a multi-GEM structure with a reflective photocathode deposited on the top of the first GEM in cascade. The multi-GEM/MHSP electron multipliers are very important in imaging gaseous detectors, given its superior ion back-flow reduction [13] relative to multi-GEM multipliers, a very important issue in GPMs.

II. THE IMAGING SYSTEM

The imaging micropattern gas detectors are depicted in Figs. 1-2 (for details see references [14, 15]). For X-ray imaging we investigated two configurations of gas detectors using charge amplification: a gas detector incorporating cascaded-GEM multipliers (Fig.1(*a*)) and other with cascaded-GEMs followed by MHSP (Micro-hole & Strip Plate [2]) multipliers (Fig.1(*b*)).

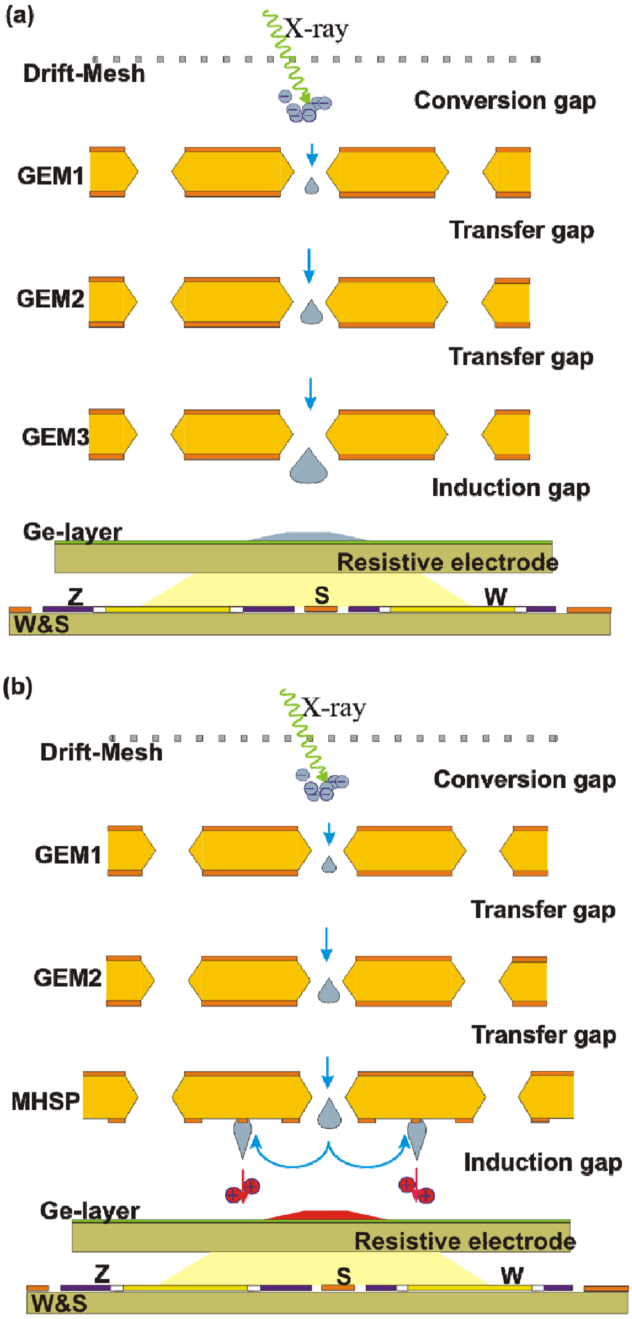

Fig. 1 - Schematic views of the X-ray imaging detectors coupled to W&S readout through a resistive electrode: (*a*) 3-GEM detector and (*b*) 2-GEM/MHSP detector.

For single UV-photons imaging we investigated a gas photomultiplier (GPM) based in a multi-GEM multiplier coupled with a reflective CsI-photocathode deposited on the top surface of the first GEM in the cascade (Fig. 2). As a readout element we used a simple/economic charge-interpolative Wedge & Strip (W&S) readout-electrode [16], localized below a resistive electrode used to broaden the charge distribution and matching its width to the readout pitch. The detectors were operated with an Ar/5%CH4 gas mixture at 1 atm.

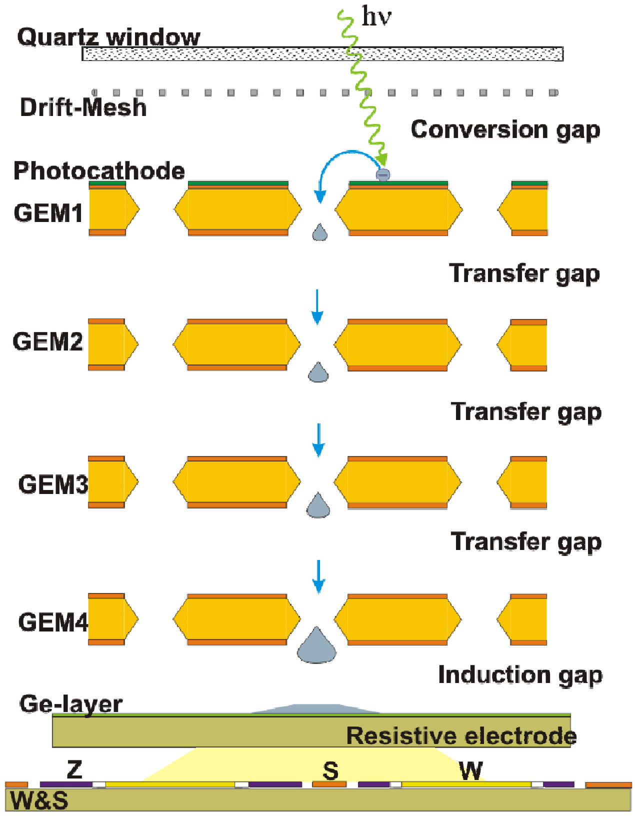

Fig. 2 - Schematic view of the 4-GEM GPM (with a reflective CsI-photocathode deposited on the top-side of GEM1) coupled to W&S readout through a resistive electrode.

The position enconding electronics used with the W&S readout-electrode having three channels is based in the standard electronic chain consisted in charge preamplifiers followed by linear amplifiers, combined with a PC-based data acquisition (DAQ) system (Fig. 3). The DAQ is based on a National Instruments PCI-6115 board, having four simultaneously-sampling analogue inputs (10^7 samples/s) connected to 12-bit ADCs, which are software-configured and calibrated. An algorithm written in LabView for Windows was used to communicate with the DAQ-board, allowing the pulse sampling, digitalization, data manipulation and storage in the PC's hard-disk, or displaying the data on-line on the PC's screen; the DAQ system was used for pulse-height analysis and for the computation of the centroid position of the charge distribution recorded by the W&S readout.

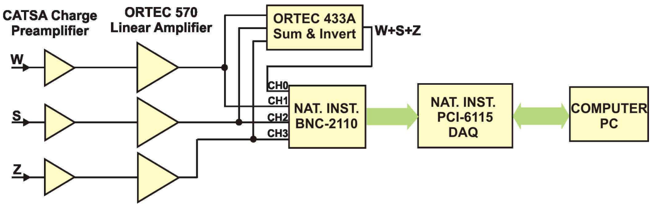

Fig. 3 - Block diagram of the position encoding electronics used with the W&S readout.

III. EXPERIMENTAL RESULTS

For the 3-GEM detector (Fig. 1(*a*)), spatial resolutions of ~70 and ~50 µm RMS were obtained in *x*- and *y*-directions, respectively, for 5.9 keV X-rays. The detector was operated at effective charge gain of ~3×10^4 and presented an energy resolution of ~18% FWHM [15].

The Fig. 4 presents a 2-D X-ray image, with a width of ~9×12 mm^2, of a stainless-steel slit-mask placed on the window of the 2-GEM/MHSP detector (Fig.1(*b*)), irradiated with 5.9 keV X-rays from a ^{55}Fe X-ray source localized ~70 cm away from the mask. The detector was operated at an effective charge gains of ~1.6×10^4, having an energy resolution of ~18.8%. As it can be seen, slits 300 µm apart, are well resolved. Spatial resolutions of ~105 and ~85 µm RMS, were obtained in *x*- and *y*-directions, respectively [15]. Note that the limit imposed on the spatial resolution by photoelectron and Auger electron range in the gas mixture is ~40 µm RMS.

The high signal-to-noise ratio measured with these X-ray imaging gas detectors, allowed a full detection efficiency for the charges deposited in the gas medium and, therefore, each individual photon could be detected with a high efficiency, independently of its pulse-height. This is very important for X-ray radiography, permitting the reduction of the radiation dose on the patients.

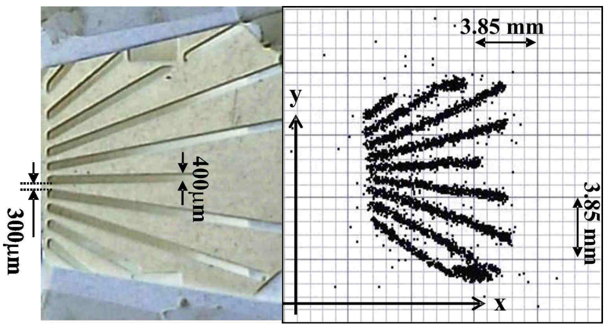

Fig. 4 - A 2-D X-ray image (right) of a stainless-steel slit-mask (left) placed on the window of the 2-GEM/MHSP detector (Fig. 1(*b*)).

Fig. 5 shown a 2-D single-photon image of an 18×14 mm^2 metal mask obtained with the GPM (Fig. 2)). The letters etched in the mask have ~120 µm trace width and ~2 mm height. The mask was mounted inside the gas chamber, 3.0 mm above the photocathode, replacing the drift mesh (Fig. 2). The image was recorded irradiating ~150 mm^2 of the mask with a continuous UV Hg(Ar)-lamp, 185 nm (6.7 eV), collimated to ~∅1 mm at a distance of ~25 cm. Letters separated by 200–300 µm are well resolved, demonstrating the good spatial resolution of the photodetector. Position resolutions of ~105 µm and ~65 µm RMS for the *x*- and *y*-directions were measured, respectively. However, the single-photoelectron detection efficiency is in the few % range [14, 15]. The imaging GPM was operated at an average avalanche gain ~5×10^5, using a high threshold gain, typically > 10^6, for image acquisition.

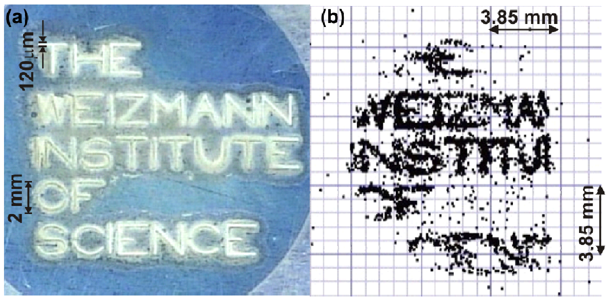

Fig. 5 - A metal mask (*a*) and the respective 2-D single-photon image (*b*) recorded with the 4-GEM GPM (Fig. 2).

The exponential-shape of the single-electron avalanche gain distribution results in large fluctuations in the total avalanche charge per UV-photon detected, introducing a strong dependence of the measured spatial resolution on the threshold used to discriminate between signal and noise. This problem is overcome with the detection of high levels of photons. In situations where is mandatory the detection/imaging of single UV-photons with high detection efficiency, another noiseless charge readout element should be used.

IV. SUMMARY

X-ray detectors based in a 3-GEM cascade or in a 2-GEM/MHSP cascade have been tested for 2-D imaging. For single UV-photon imaging, we used a GPM based in 4-GEM cascade with a reflective CsI-photocathode deposited on the top electrode of the first GEM. All detectors where coupled to a W&S readout-electrode through a resistive electrode.

We demonstrated the feasibility of simple, low-cost gas micropattern detectors in X-ray and single UV-photon imaging, with spatial resolutions of ~100 µm RMS.

These results are very encouraging, and further applications in PET imaging based on liquid xenon and in GPMs start to be considered [12]. Applications of multi-GEM/MHSP electron multipliers to digital radiography could be a possible alternative.

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